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CCLXIV.

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THE PRESERVATION OF THE FALLS OF ST. ANTHONY.

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READ AT THE ANNUAL CONVENTION, ST. PAUL, MINN., JUNE 21ST, 1883.

WITH DISCUSSION.

I.—DESCRIPTION OF LOCALITY AND HISTORY OF THE WORK PREVIOUS TO THE TIME OF COMMENCING THE BUILDING OF THE DYKE.

The Falls of St. Anthony are on the Mississippi River, about 2 000 miles above its mouth. The thriving city of Minneapolis, Minnesota, occupies both banks of the river in the vicinity of the falls, and the prosperity of the city is due to the great water power, so easily utilized, fur-

nished by the river falling 40 feet. The river-bed and banks at the crest of the falls are of limestone belonging to the upper magnesian.

Under the bed of the river at the crest the thickness of the limestone is only 11 feet.

Under the limestone is a soft sandstone called the St. Peter, so soft as to be easily excavated with a pick. The recession of the falls up stream before any protecting apron was constructed was quite rapid, and especially so when the owners of the water power built dams jutting out into the river above the falls and concentrated its whole flow into a width of not more than 300 feet. This stream of water washed out the soft sandstone under the limestone, and the latter fell down and was soon disintegrated by the rushing waters and carried away, and fresh undermining commenced. At the Falls of St. Anthony the river is divided into two channels by Hennepin Island. The east channel is entirely closed by dams, and the whole flow of the river, except what goes through the turbine or other wheels, passes over the main falls. The ordinary high water discharge of the river is about 50 000 cubic feet per second, and at extreme low water about 4 200 cubic feet per second.

By the building of dams the fall of river is increased to 50 feet. The limestone forming the bed of river only extends up stream some 900 feet above the crest of the falls, and at its upper edge is only 18 inches thick.

The recession of the falls from the time of the construction of the mill dams (1857) to 1870 was from 350 to 600 feet. The part that receded 600 feet was in the middle of the falls, in the west or main channel.

In 1866 an apron of wood was commenced but not finished, and what was built was almost destroyed the succeeding spring. Another attempt in 1869 to construct an apron was interrupted by an unseasonable high water.

In September, 1868, a company known as the Tunnel Company commenced the excavation of a tunnel from a point near the foot of Hennepin Island, up under that island and up to a point under the next island above, called Nicollet Island. The tunnel was designed as a tail race for the water that was to be used in turning the machinery of manufactories to be built on the lower end of Nicollet Island. On the 4th of October, 1869, this tunnel was excavated just to the foot of Nicollet Island (see accompanying map, Plate XXVI). Here the water rushed into the tunnel from the river above, and soon the tunnel was filled with a great stream of water that rapidly enlarged it from its excavated size, 6 x 6 feet, to

widths varying from 10 to over 100 feet and to a depth 16 feet below the lime rock.

After much difficulty, and after using several devices, such as sinking timber rafts over the cavity in the lime rock through which the water rushed (see plate), the citizens succeeded in surrounding the opening with a coffer-dam.

October 20th a large mass of the limestone forming the bottom of the river between Nicollet and Hennepin Islands (see the plate) fell into the washed-out cavern below, and again the waters of the Mississippi rushed through the tunnel, and were only stopped by a coffer-dam built around this second break.

An attempt to close the tunnel just below this break during the winter, by building a bulkhead of timber made water-tight with clay and straw, and puddling the bottom of the cavity above, was made, but the high water of the spring following partly destroyed the coffer-dams, and the water washed out the sand rock at both ends of the bulkhead and soon destroyed it, and at the lower end of the tunnel the undermining was so great as to destroy several buildings on the lower end of Hennepin Island. The next attempt to close this break was to fill it with a crib-work of logs and cover it with a water-tight covering. This was effective during the season of 1870.

The eminent hydraulic engineer, Mr. James B. Francis, was employed in May, 1870, to make a plan for the preservation of the Falls of St. Anthony. He recommended—1st, that a substantial apron should be immediately constructed to prevent the farther recession of the falls.

2d. To protect the already thin layer of limestone that formed the bed of the river at the crest of the falls from the effect of frost and ice, that two low dams should be constructed just above the falls to keep this bed rock always covered with water below the action of frost ; and

3d. That the tunnel should be uncovered from the upper end of Hennepin Island for about 400 feet below, all débris cleared out of it, and the entire cavity filled partly with masonry, but chiefly with a puddle of clay and gravel.

The cities of Minneapolis and St. Anthony and the Water Power Company commenced work on the present apron in July, 1870. By act approved July 11, 1870, Congress made an appropriation of $50 000 for the preservation of the Falls of St. Anthony. The work was placed in charge of Col. J. N. Macomb, Corps of Engineers, U. S. Army. The

local Superintendent of the work was Mr. Franklin Cook. Operations were commenced August 9th, 1870. The plan adopted was as follows:

To clean out the first break and fill it with cross walls of masonry, and good clay puddle up to the top of the limestone.

Then to build a masonry wall on the limestone from Nicollet Island, above the cavity and out around it, thence down parallel with the west bank of Nicollet Island to surround the second break, and then to the lower point of Nicollet Island. This wall to be built to above high water and the space between it and Nicollet Island to be filled with gravel. Great trouble was experienced in cleaning out the upper cavity on account of the water coming through the soft layers of sand rock near its bottom from the river.

The earthen embankment (shown on the plate) in the main river was made to fill up holes in the river bed, from which it was supposed the water came. By act approved March 3d, 1871, $50 000 was appropriated for this work. On July 4th, 1871, before the wall was built, a new break occurred.

This was from a break through the limestone (marked on the plate) in the St. Anthony mill pond, and under the limestone to the main tunnel, just under the foot of Nicollet Island. This new channel or break was under the limestone, 12 to 16 feet wide, and about 16 feet high. Before the water could be shut out from this break the lower end of the tunnel became choked with débris, and a new mouth to the tunnel was made emerging into the river, just below the eastern end of the falls of the main river. This is known as the west branch of the tunnel. To cut the water of the river off from this last break, a dam was constructed from the head of Nicollet Island to the left bank of the river, and as soon as this was done a coffer-dam was built out from Nicollet Island, surrounding the break, and joining on the coffer-dam built to protect the lower break.

This last incursion of the river thoroughly alarmed the citizens of Minneapolis, and active efforts were at once made to do something to secure the falls, that seemed to be doomed to destruction.

But it will be seen that the thought of still utilizing the unfortunate tunnel as a tail-race governed the minds of those directing the work for the preserving of the falls.

By September 1st $90 000 was secured, and the following plan carried out to prevent any enlargement of the now too large tunnel:

"First, all loose materials in the tunnel were removed; commencing at the lower end of the west branch, the sides of the tunnel cut perpendicular, and the bottom excavated to the level of the level of the deepest part. The bottom was then covered with a layer of broken stone, on which a grouting of cement was poured. On this layer cross timbers 10″×12″ were laid, and on their ends posts of the same cross section were put, extending to the limestone overhead and wedged to it. These uprights were 30 inches from the vertical sides of the tunnel.

"To prevent these uprights from being pushed in, struts were put across at their middles and tops.

"Outside of the uprights 4-inch planks were placed, and between the plankings and the sides of the tunnel a filling of broken stone and grout, put in in layers of 8 to 10 inches in depth, was placed.

"The upper layers were of brick, laid in cement mortar and carefully connected with the limestone. Between the sills layers of broken stone and grout were put, until the upper surface of the sills was reached. On the sills were spiked a flooring of 4-inch plank, and on this again were put cross timbers 10″×12″, joined into the side posts, to resist any upward pressure from below."

By August, 1872, 800 feet of this lining were completed, and a timber bulkhead put across the tunnel at 1 400 feet from its lower end. This work was carried on by means furnished by the people of Minneapolis.

In the meantime the funds appropriated by Congress were being used in clearing out the last break (in St. Anthony mill-pond) and in building a cross wall just below the break, with wings extending from the bottom of the cavity to the limestone rock, and in putting a layer of clay puddling on the sand bottom of the river, just above where the lime ended. This work on the east side of Nicollet Island was then turned over to the Citizens' Committee, who filled the cavity in St. Anthony mill-pond with gravel, and on this filling put a flooring of timber. At the same time the wall across the first break was completed.

By act approved June 10th, 1872, Congress appropriated $50 000 to carry on this work.

On August 10th, 1872, the Board of Officers of the Corps of Engineers U. S. Army, consisting of Col. J. N. Macomb, Lieut.-Col. J. D. Kurtz, Major G. Weitzel, Major O. M. Poe and Major D. C. Houston, met at Minneapolis to consider and report upon the whole subject of the pres-

ervation of the Falls of St. Anthony and the works then in progress therefor.

The Board approved the plan proposed by Col. J. N. Macomb, viz. : to commence a wall at the southerly side of the main wall already built, and carry it across the entire width of the river, near the head of the limestone ledge, commencing the foundation at the hard stratum 14 feet below the bottom of the ledge, bringing it up even with the top of the ledge and joining it on to the same, filling all places above this wall where the sand rock had been washed out with puddle and rip-rap. But the plan involving a cost far in excess of the funds available, the Board recommended that the appropriation be expended in strengthening, as far as necessary, the coffer-dams already built around the gorge, and in continuing the lining of the tunnel on the plan already adopted. The Board further recommended that $37 500 of the appropriation be applied, in accordance with a petition of the citizens of Minneapolis, to the completion of the lining and building a masonry bulkhead at the head of the tunnel, and that the balance of the appropriation be expended under the direction of the engineer officer in charge of the works constructed by the United States in maintaining and strengthening them as far as found necessary.

Early in September Capt. W. H. Benyaurd, Corps of Engineers, took local charge of the work, under orders from Col. J. N. Macomb.

Work on the extension of the lining was commenced October 3d, 1872, and had progressed but a very short distance when an increase of the amount of water coming into the tunnel from above was noted, and it was thought best to at once construct the bulkhead. This bulkhead was built of limestone masonry 28 feet in thickness, and had two openings through it, provided with fly-gates to carry off water from above and the lining was extended above the bulkhead for 100 feet. Funds being exhausted, work was suspended February 16th, 1873.

By act approved March 3d, 1873, Congress appropriated $50 000.

In the latter part of March work was resumed with a small force in raising and strengthening the coffer-dams, and everything was thought secure, when, on April 15th, the coffer-dam on the east side of the lower break was pushed in, and through a gap 150 feet the water poured into the space surrounded by the coffer-dams.

The entire space was flooded, and one workman was drowned. Means

were at once taken to close the break and to strengthen the other dams and the earth embankment.

The writer relieved Col. J. N. Macomb April 25th, 1873, Assistant Engineer James P. Allen being in local charge from that date until May 17th, when, at his own request, he was relieved, and Assistant J. L. Gillespie was put in charge, and continued in that position until the completion of the work.

When the coffer-dams were repaired and the water drawn off, it was found that the masonry bulkhead had been undermined and destroyed.

On May 17th a fresh break occurred in limestone ledge under the earth embankment (marked on the plate), the water from it finding its way to the lower break through a new channel under the limestone.

The flow of water through the tunnel was limited to that which could pass through an opening 4′×2′ in the wooden bulkhead put in at the time the citizens constructed the lining. Until the river had subsided somewhat, the work of repairing and strengthening the coffer-dams and in protecting the outer face of the earth embankment was carried on. Then the tunnel was drained and a timber bulkhead, with the interstices filled with concrete, was built, with its lower face under the shaft some 250 feet below the lower breach. Through it and the tunnel above to the upper end of the break, at foot of Nicollet Island, a 36-inch cast-iron pipe was laid, and the tunnel for the same distance filled with carefully rammed gravel. In addition, several concrete cross walls were built across the bottom of the tunnel, extending 4 feet below its bottom, to prevent any undermining. This work was completed November 29th, 1873, and the valve in the pipe at the lower face of the bulkhead was closed. The bulkhead proved water-tight, but an alarming increase of water, flowing through a 7-inch pipe at the junction of the west branch with the main tunnel, convinced those in charge of the work that this water came from above the bulkhead, through a passage outside of the lining of the tunnel.

Some careful observations showed also that there must be some large cavities along this outside channel. The valve at the bulkhead was opened and the space inclosed by the coffer-dams drained.

The pipe through which the water came into the main tunnel was put in by the workmen in lining the tunnel, and when the United States assumed charge of the work its mouth was covered with sand, and as no record had been kept of the position of the pipes through which water

was admitted into the tunnel, its existence was not known until after the valve was closed. As the funds were almost exhausted, the citizens of Minneapolis subscribed and placed in the writer's hand for disbursement the sum of $17 157.50, to be expended in attempting to cut off the connection believed to exist between the channel from the break in St. Anthony mill-pond to the lower break, and the channel to the pipe below the bulkhead. This was done by cutting down on the lower side of the first channel to 16 feet below the limestone and putting in a 12-inch drain-pipe from the break in St. Anthony mill-pond to the lower break; this reduced the flow from the pipe from 230 gallons to 80 gallons per minute.

The lower half of the west channel from the west break to lower break was cleaned out, a drain-pipe put in and filled with gravel.

Being convinced that the sandstone under the limestone was traversed by many threads of water which might enlarge, and then the limestone be undermined as before and the falls destroyed, and finding from borings that the first hard stratum of the sand rock was some 38 feet below the limestone, the writer submitted a plan for constructing a wall or dyke entirely across the river, extending from the limestone down to the hard stratum, which would completely cut off the flow of water from the river above through the soft sand rock under the limestone to the river below.

On April 15th, 1874, a board of engineers, consisting of the same officers as the previous one, except that the writer was substitued for Major Houston, met in Minneapolis to consider the subject of the preservation of the Falls of St. Anthony.

The board, after carefully considering the circumstances existing at the time of their meeting, recommended that the following plan be carried out to preserve the falls:

1st. That two dams of timber and stone should be constructed on the limestone ledge above the crest of the falls, one whose lower face should be on the prolongation of the main slope of the wooden apron protecting the soft rock below the falls, and the other about half-way up stream between the lower dam and the upper extremity of the limestone on the bottom of the river. These dams should be high enough to protect the limestone from the action of frost.

2d. The apron at the falls be put in thorough repair and extended down stream on the west side of Hennepin Island.

3d. The construction of a concrete dyke or wall extending from one bank of the river, whose bottom should be on the hard stratum, some 38 feet below the limestone ledge and its top just under and connected with the same. The line of the dyke to be not nearer at any point to the falls than 160 feet. The least thickness of the wall to be 4 feet.

In addition, the board recommended that the dyke recommended by the board of 1872 should be constructed after the other was finished, and that the lower dyke was recommended because of the less difficulties in the way of its construction, and because of the necessity of more speedy work being done. By act approved June 23d, 1870, Congress appropriated $125 000 to commence this work, and the writer received orders to carry out the above recommendations of the board.

II.

History of the Work of Constructing the Concrete Dyke for the Preservation of the Falls of St. Anthony.

The work of sinking a shaft through the limestone ledge was commenced July 9th, 1874. The shaft was located on Hennepin Island (see Plate XXVI) over the line of the tunnel beneath, below the outlet of the west branch. At a depth of 30 feet below the surface the under side of the limestone was reached.

A good deal of water coming in from the seams in the rock, the shaft through the limestone was lined with concrete and timber. The shaft had a horizontal section in the clear of 14 by 16 feet, which was divided into two parts, one of which was used for hoisting purposes, and the other for a stairway for men and for the pump shafting. The shaft through the limestone was completed August 28th.

In order to secure drainage and an outlet for the water to be raised by the pumps as the work progressed, a drift 4 by 8 feet was excavated just below the limestone in the sand rock, on the line of the proposed wall, to the west branch of the tunnel.

A 42-inch turbine wheel, of a pattern known as the American, was set up at the mouth of the west branch of the tunnel, and a flume carried to it from Farnham & Lovejoy's pond. The power was transmitted to the shaft by means of wire rope running on sheaves 14 feet in diameter.

Centrifugal pumps, with vertical axes, set in portable wooden frames,

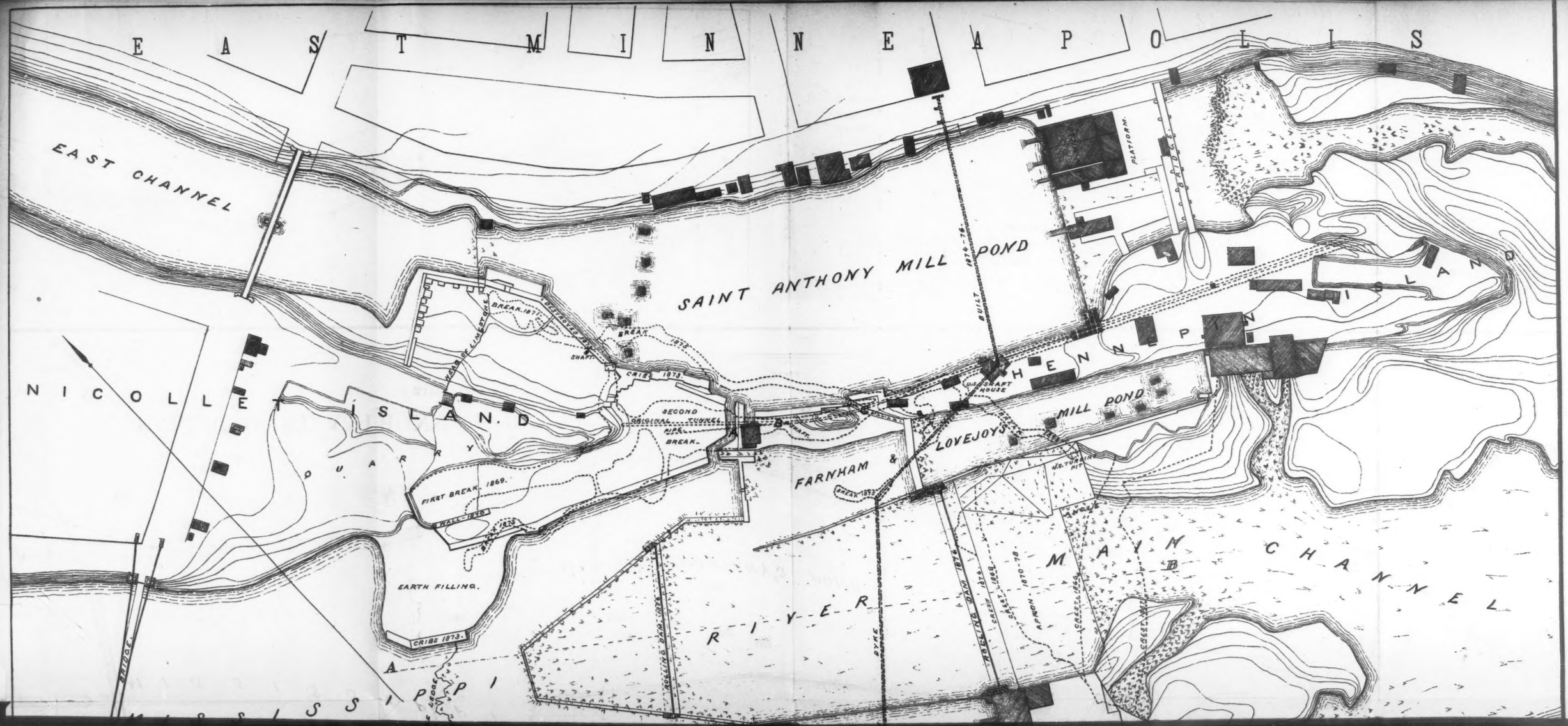
were used to pump out the water, the pumps being lowered as the work of sinking the shaft progressed. The progress through the quicksand in the bottom of the tunnel, about 25 feet deep, was very slow. Streams of water were met with as the excavation was carried downwards, but generally as new streams developed those above them ceased flowing. When streams were found in the sand rock, excavations in the side of the shaft were made and iron pipes inserted to carry the water, and the excavation filled with puddling and béton. When the shaft was carried to a depth of 45 feet below the lime-rock it was lined with brick, backed and bottomed with béton, and when the béton had thoroughly set the pipes above mentioned were all plugged up. Two centrifugal pumps were then set in permanent positions. As soon as the pumps were ready and the hoisting machinery, tracks, &c., in readiness, headings to the east and west of the shaft, on the line of the proposed dyke, were commenced. The bottoms of these headings were 39 feet below the limestone, and the size about 4 feet wide by 8 feet high.

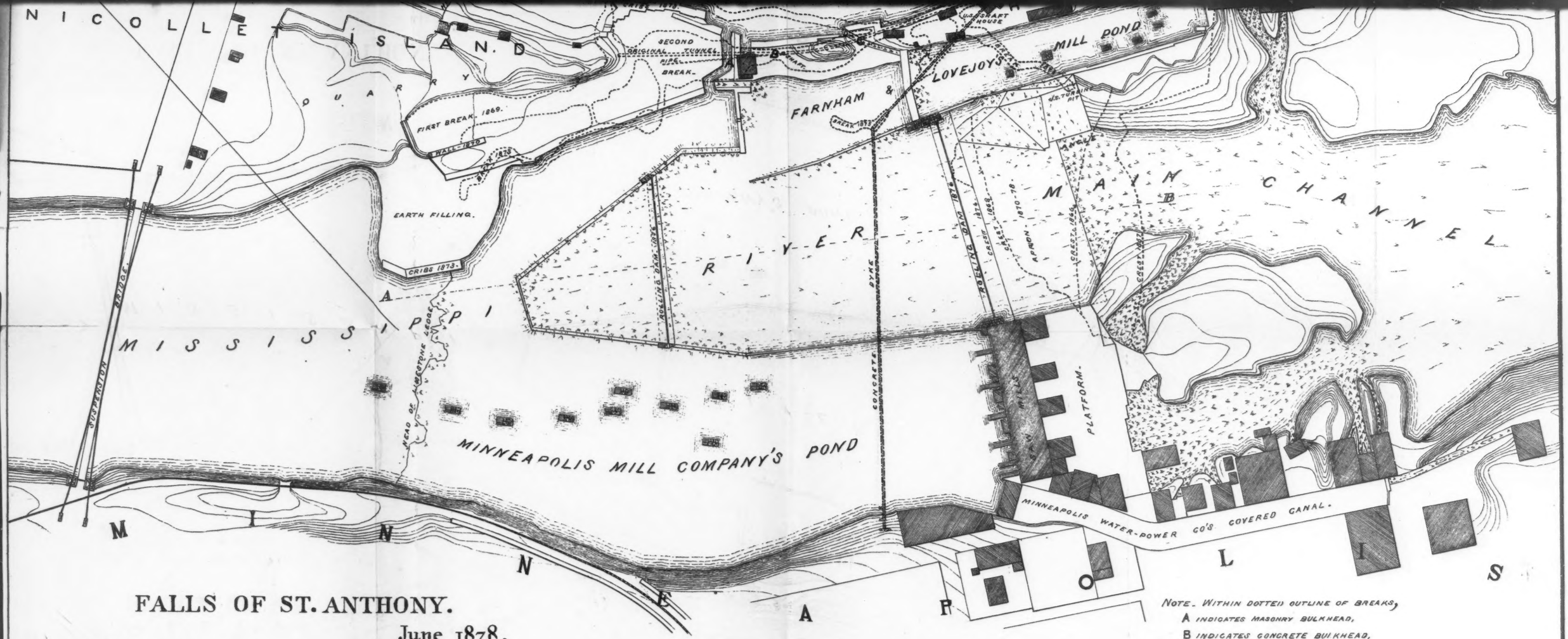
The first plan pursued was to simultaneously drive two headings, one at the bottom of the proposed wall and one just under the limestone, each about 100 feet long, laying the foundation of the dyke as the lower excavation progressed.

In the foundation a 12-inch drain-pipe was laid. Then the sand rock between the upper and lower drifts was excavated and the wall built up to the level of the upper heading. An arched passageway 3½ feet wide and 7 feet high was left in the wall just above its foundation.

The side walls of this passage were 18 inches thick. At intervals the passage was widened to 7 feet to allow a double track. This plan of operations was soon modified, as a great deal of timbering was necessary to hold up the sand rock in the lower heading.

It was found better to make a heading the entire height of the wall, in sections of about 30 feet in length. As far as practicable the sand rock excavated was brought out on the upper passage to where the dyke crossed the west branch of the tunnel, and thence to the mouth of the west branch, where it was dumped into a flume that carried it to the river. Each section of the wall, as built, had its outer end in an inclined plane, up which the excavated material from beyond was hauled to the upper passage. At intervals vertical shafts between the upper and lower passages were made in the wall and sumps for collecting sand brought in by the streams of water and from the excavations at headings.


EAST MINNEAPOLIS
EAST CHANNEL
SAINT ANTHONY MILL POND
NICOLLET ISLAND
HENNEPIN ISLAND
MILL POND
QUARRY
FIRST BREAK 1869.
BREAK 1871
DESTROYED BY
SHAFT
CRIB 1873
SECOND
ORIGINAL TUNNEL
PIPE
BREAK.
BREAK 1875
EARTH FILLING.
CRIB 1873.
BREAK 1873
FARNHAM &
LOVEJOY'S
SHAFT HOUSE
PLATFORM.
OUTLET 1874-76.
MAIN CHANNEL
MISSISSIPPI
RIVER
ROLLING DAM 1876
APRON 1870-76
CREST 1868
CREST 1870
BYAK
EDGE
INLET



FALLS OF ST. ANTHONY.

June 1878.

NOTE. WITHIN DOTTED OUTLINE OF BREAKS,
A INDICATES MASONRY BULKHEAD,
B INDICATES CONCRETE BULKHEAD,
C INDICATES TIMBER BULKHEAD.

PLATE XXVI
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The concrete for the wall was mixed at the head of the shaft in an automatic or box mixer, and that for the foundation and side walls was lowered to the bottom of the shaft and taken through the passage in the completed wall to the heading.

As soon as the side walls and the centres for the arch were in place, the concrete was taken along the upper track and dropped. The concrete was well rammed in layers of about 6 inches in thickness. As the work progressed it was found difficult to keep the 12-inch drain-pipes clear of sand, so an open drain was substituted. Whenever streams of water were met, iron pipes were inserted in the sides of the excavation and the water led to the drain. As soon as the concrete was thoroughly set and the wall carried a sufficient distance beyond the pipe, it was plugged.

Frequent tests of the temperature of the water entering the headings were made, and generally the temperature of the water from the up-steam side was about 51° F., and that of the streams from the down-stream side pipes were nearly the temperature of the river water. As a rule, the amount of water entering the excavation was easily pumped out by one No. 6 Heald and Cisco pump, and amounted to about 700 gallons per minute. The difficulties that were encountered all resulted from water coming in from the river above, through some fissures in the rock. When such incursions of water came a great deal of sand came with them, and in some cases filled the drains and choked the pumps. On April 9th, 1875, the river rose suddenly and a great quantity of water came over the dam on Hennepin Island and poured down the shaft, completely flooding the work. Fortunately an accident to the turbine wheel had stopped the pumps, so no men were below. Immediately following this, the coffer-dam in the east pond broke and a new channel from it under the lime rock into the excavation to the west of the west branch was developed.

This new channel passed under the main tunnel, and it was only when the lining of the tunnel fell in, and the water passed along the lined tunnel below, that a great danger was averted.

The coffer-dam was repaired, and the new channel filled with well-rammed gravel. July 8th, 1875, a large stream of water was encountered 370 feet west of the shaft. This came through a fissure about 30 feet below the lime rock.

It brought in a great quantity of sand, which caused much trouble.

A search in the old washed-out channels on the west side of Nicollet Island revealed the source of the trouble, and steps were taken to drain the water into the main channel. The sand brought in by this break was so great a quantity as to take 18 days of day and night work to remove it. In November, 1875, the east branch of the dyke reached its furthest limit, 600 feet from the shaft, and in March, 1876, the west branch was completed except the filling of the upper and lower passages, a distance of 1 275 feet from the shaft. Two spurs 25 and 50 feet from the ends of the wall were built on the up-stream side of the wall, and a T at the ends. In filling the lower passage in the wall, a pipe leading from the upper side of the wall was carried from the angle in the dyke west of the shaft to the shaft, and thence up the shaft.

Another pipe was brought from above the wall at the shaft, up the same. Holes were bored in these pipes 1 foot apart, and by means of glass gauges the height of the water behind the dyke was measured.

The whole wall was completed in December, 1876.

Except on Sundays, and when driven out by water, the underground work was continuous day and night, by gangs of men relieving each other at intervals of 8 hours. The stone for the concrete was quarried mostly from near the foot of Nicollet Island, from the bed of the river, within the areas enclosed by coffer-dams.

It was crushed in a Blake stone crusher. The sand came from street grading work in East Minneapolis.

The cement used was, for the foundation and side walls of lower passage, the Black Star Louisville, and for the remainder Utica, Ill., and Buffalo and Ackron.

As it was some distance from the mixer to where the concrete was placed, a slow-setting cement was used. The proportions used were by measure 1 part of cement, 2 parts of sand, and 5 parts stone. The water used was from the river. In the winter the water was heated by steam. Fresh air was supplied to the headings by means of pipes leading from an air compressor in the shaft-house. When the distance of the end of the west heading was beyond 400 feet from the shaft, a portable engine supplied with steam from a boiler in the shaft-house by means of a hose was used to hoist the excavated sand to the level of the upper heading. The exhaust was carried down into the drain-pipe, and no inconvenience was occasioned by the escaping steam.

The cost of the work of constructing the wall was as follows:

Labor, excavating the sand rock, per cubic yard	$3.06
Labor, quarrying, delivering and crushing stone for concrete, per cubic yard	1.48
Labor, mixing, placing and ramming concrete, per cubic yard	2.07
Handling, testing, &c., cement	.04
Labor, handling sand	.05
Labor about machinery	1.02
Total cost of labor	$7.72
Cost of plant used	1.77
Office expenses	1.00
Materials (cement and sand)	3.67
Total, per cubic yard of dyke	$14.16
Total number of cubic yards in dyke	14.882
Total cost of dyke	$210 729.00

From July, 1874, to July, 1875, the cost of labor was $14 per cubic yard of wall built, while during the remainder of the work the cost of labor was less than $7 per cubic yard.

This difference is due to the enormous quantity of sand removed during the first year, which was brought into the excavation by the incursions of water from the river above, and also that all the cost of putting down the shaft and other preparatory work was in the same period.

III.—Rolling Dams and Aprons.

In accordance with the plan described in first chapter, two rolling dams of timber filled with stone were constructed on the limestone ledge in the main river.

The lower one just at the crest of the falls had its lower face on the prolongation of the main slope of the apron, and is 6½ feet high; the upper one is 5½ feet high.

Their construction was very simple, and presented no difficulties. They were built at a low water period. The lower timbers were bolted to the rock, and the several courses of timber to each other. The cover-

ing is of two courses of pine plank, one 8 inches, and the other 4 inches in thickness.

The crest of the dams are protected with tank iron ¼ inch in thickness.

These dams were built under contract, and cost $24 957.29.

In order to prevent the concentration of the water pouring over the falls in the small space of 300 feet, the west slope of the apron was rebuilt so as to be in the plane of the main slope. This required the removal of a large quantity of limestone and underlying sand rock.

The apron is constructed of timber bolted to the underlying rock. The covering is of two courses of plank 8 x 4 inches in thickness. The foot of the apron is built on timber cribs filled with stone, and from time to time a large amount of boulder rip-rapping has been thrown in to prevent the undermining of the structure.

The work of repairing and remodeling the apron was very expensive, and it will be always a constant expense to keep it in an efficient condition.

The cost of this work was, from July, 1874, to July, 1878, $63 498.72.

Section 1, Plate XXVII, shows normal cross-section of the dyke, and the several strata of the lime and sand rock.

Section 2 is a cross-section showing dimensions of dyke where the upper and lower passages were enlarged by switches.

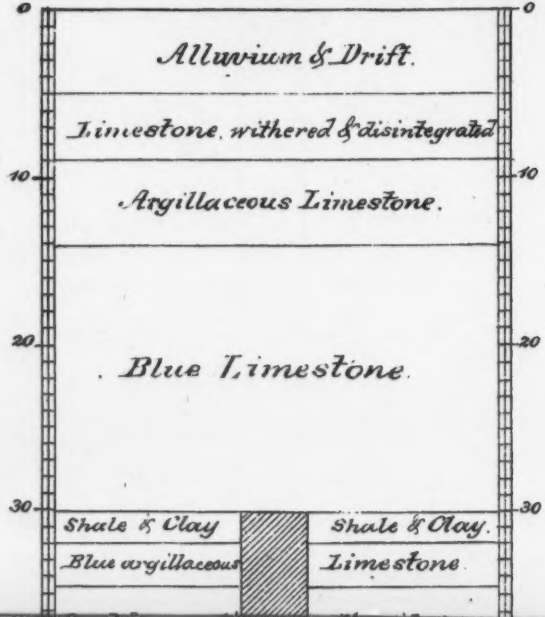
Section 3, Plate XXVIII, is a vertical longitudinal section along middle of main river, and shows section of apron.

Section 4 is a vertical longitudinal section along axis of dyke.

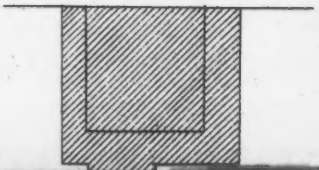
Section No. 1

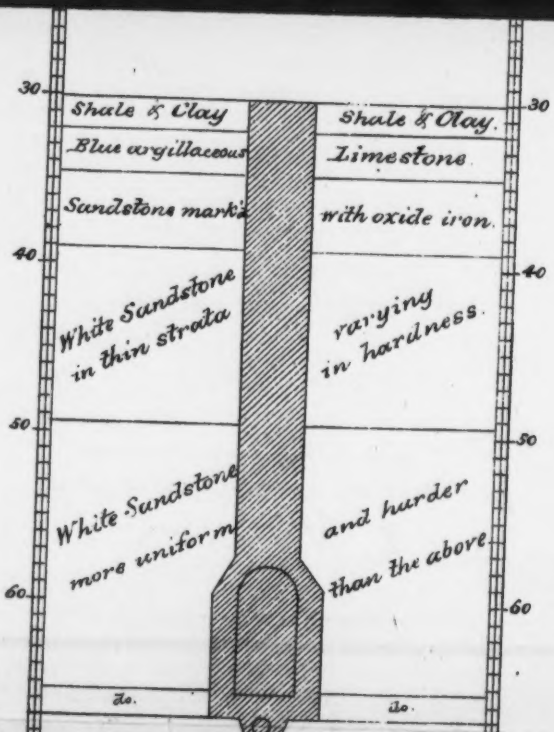
Geological Section on Line c-d

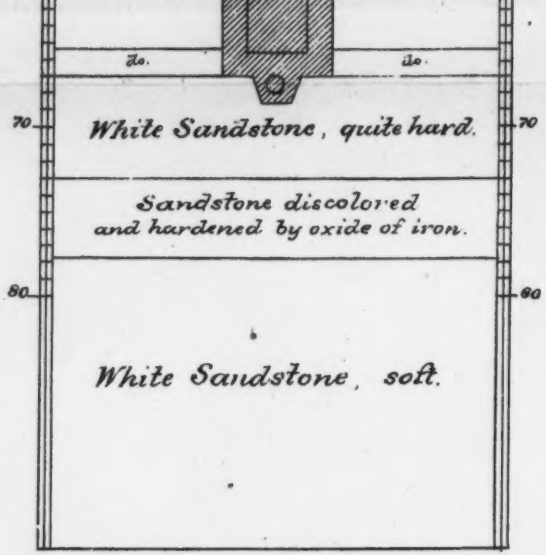
showing section of dyke. Scale 1/120.



CROSS SECTIONS OF DYKE AT FALLS OF ST. ANTHONY.




30
Shale & Clay
Blue argillaceous
Sandstone marki
40
White Sandstone
in thin strata
50
White Sandstone
more uniform
60
do.
Shale & Clay
Limestone
with oxide iron
40
varying
in hardness
50
and harder
than the above
60
do.
30



Section No. 2

Section of dyke on line e-f, showing crosssection of necessary turnouts in upper and lower drift.

Scale $\frac{1}{120}$.

PLATE XXVII
TRANS. AM. SOC. CIV. ENGRS.
VOL XII Nº CCLXIV
FARQUHAR ON
FALLS OF ST. ANTHONY.

DISCUSSION.

C. G. FORCE, M. Am. Soc. C. E.—I would like to know the cost of the dyke?

Col. FARQUHAR.—It was $210 000. A great deal was also done in building of coffer-dams, etc., before I commenced the work; but this sum included all the work that was done by the Government to protect the dam.

In the report of the Chief of Engineers, U. S. A., of 1879, a complete history of the entire work was given, including every item mentioned in this paper.

Mr. P. A. PETERSON inquired whether any water passed through the lining into the tunnel now?

Col. FARQUHAR replied that there was, perhaps, a little, but that the indication was that there was no leak through the limestone.

In response to a question by a member of the Society, Col. FARQUHAR explained that the excavation was generally made by means of a truck loading the débris into cars and hoisting up; that the wall of the tunnel was left on an inclined plane on each section, and the cars were hoisted up that inclined plane and along the top drift and brought out and dumped into the river; that this hoisting was done principally from the shaft of the Water Power Company until the work had progressed for about 400 feet, when an engine was put in and used for that purpose.

The track on which the trucks were run was a single track with turn-outs at reasonable distances. The concrete work did not, at any time, interfere with the work of excavation, the concreting being done at one end, to the eastward, and the digging being done at the westward, and the filling up being done at one end and the excavation at the other.

Major CHARLES T. ALLEN, U. S. A.—Gentlemen, the paper read yesterday by the gentleman [Col. Farquhar] upon the preservation of the Falls of St. Anthony brought the matter down to the year 1877. He gave you a full account of the construction of the concrete dyke which is intended to prevent percolation of the water through the soft sand rock, and of the dams known as the rolling dams, which were erected for the purpose of keeping the surface of the limestone flooded during the winter to prevent ice scaling off the rock.

The position of the concrete dyke is shown upon Plate XXVI.

The existence of the falls, then, depends upon the preservation of a

ledge of limestone rock about 1 200 feet in length. Its thickness at the upper edge is about 2 feet; the thickness at the lower edge about 12 feet. When the underlying rock, of soft sandstone, is undermined, the superincumbent mass falls. To prevent the destruction of this concrete dyke, this lower apron was put in, and one of the greatest difficulties of late years has been the preservation of this apron. The fall being about 45 feet, and the area of discharge of the waterway having been diminished to less than one-third of its original value by the encroachments upon the bed of the river by the mill dams, the whole mass of the flood discharged is precipitated through this narrow gorge of about 450 feet width upon the soft sandstone bed.

In 1878, when I took charge of the work, a mass of large granite boulders had been placed below the apron so that they were flush with the surface of the water. The discharge of the water through this narrow space and the movement of ice removed the boulders in the course of two or three years as though they were so much shot, and scoured the bottom out, at the end of three years so as to leave a depth of about 34 feet just below the toe of the apron. Heavy blocks of limestone, some of them weighing from 2 000 to 4 000 pounds, were afterwards thrown in, as far as the money available for expenditure would admit of, and they were also carried out. A large portion of the damage was due to the obstruction to the flow of the water caused by the deposit of large masses of débris from the excavations for flouring mills on the west side of the mill-pond. The largest dam formed by this débris was about 120 feet in length and rising to a height of 18 feet above the water's surface. You can easily see what the action of the water was in this angle by referring to Plate XXVI, and its effect in scouring out the bottom. It became evident that some steps must be immediately taken to prevent this further encroachment and erosion, particularly as this point [the angle] was nearest to the concrete dyke, and was also near the opening of the west branch of the tunnel—a break which was originally started by the attempt to make a tail race under the limestone.

During last fall a large amount of rip-rap was placed in the angle for a distance of about 130 feet down stream, and about 120 feet measured along the toe of the apron, the average filling being about 9 feet. On top of this rip-rap was sunk a large crib of timber, 80 feet on a side and about 6 feet in depth. The crib was strongly floored and filled up with small stone and grouted. Of course, the weight of the crib under those

circumstances would be very much greater that the weight of water displaced. The details of this work and the drawings can be seen in the room upstairs. These repairs cost about $35 000, the crib costing about $9 000.

To further ensure the protection of the apron, the same system of crib or mattress of timber will probably have to extend across the whole distance or width of the river below the apron, unless provision eventually be made for discharging more of the water through its original bed.

The cost of the work from the commencement has been about $940 000, of which $600 000 have been expended by the United States Government, and $340 000 by the citizens of Minneapolis in the earlier stages of the work.

Having brought the narration down to this point, I do not know that there is any more that I can give of interest in addition to the paper by Col. Farquhar which you heard read yesterday.

A MEMBER.—I would like to ask Major Allen whether he is informed as to the total amount of horse power there is at the falls, and that can be utilized, and the amount that is at present utilized.

Major ALLEN.—The number of horse power that can be utilized and that is utilized depends, of course, upon the extent of the fall utilized. The plunge over the apron is about 45 feet, but by appropriate arrangement of sluices and canals a greater head can be developed. The question of the amount of horse power and its present and prospective availability will be treated upon so fully in the paper promised you concerning the Falls of St. Anthony that anything I could say now would not be of very great additional value. The gentleman who is to read that paper has been associated with the falls for a great many years, and is thoroughly conversant with the matter of which he speaks. I refer to Mr. Frizell.

Mr. COLLINGWOOD.—I would like to inquire as to what is the position of the cribs that were sunk there. In what position were they placed with reference to the dam itself ?

Major ALLEN.—The cross-section through this dam and apron would show a fall of about 45 feet. This angle is shown on Plate XXVI. After this map was made, and prior to my taking charge of the work, a timber protection to this easterly bank was extended down stream for several hundred feet. The space between the apron and this extension is what is called the angle. This crib, which was to prevent further erosion, was sunk directly in the angle where the greatest scour and the greatest abrasion occurred.

Mr. HERMANY.—I would ask of Major Allen to what extent the power is affected by back-water during flood time?

Major ALLEN.—That is a subject I have never fully investigated—that is, the matter of the water power at the falls. The preservation of the works was all I was entrusted with.

A MEMBER.—I would like to ask what the interest of the Government was in the matter. Was it simply the purpose of the Government to preserve the navigability of the river below, or had it reference wholly to preserving the water power here?

Major ALLEN.—The preservation of the falls was undertaken by the General Government about 1870, the plea for their preservation being that the destruction of the falls would convert the river above them into a series of shoals, reefs, etc., and thereby destroy steamboat navigation; and shortly after the first appropriation was made for the falls, a small appropriation was made by the General Government for the removal of boulders and other obstructions in the river above, but nothing has been expended there for a number of years past.

Mr. HERMANY.—I will put my question in another form. Is the height of the falls determined by the height of the plunge?

Major ALLEN.—The height of the plunge, properly speaking, the fall, is greater *now* at high water than it was before the bed was occupied by the Water Power Company's dams. If the question means, are the falls drowned out during high water, my answer is No; the head is not appreciably diminished during high water.

CHARLES E. EMERY, M. Am. Soc. C. E.—In private conversation upon this subject, it was suggested that possibly the Government and private citizens had already spent enough money here to have bought and maintained steam engines sufficient to produce the power. That is hardly probable; the $940 000 mentioned would only maintain continuously, forever, from 1 500 to 1 800 horse power, according to ruling prices, as can be found by consulting my paper. Could further expenditures be included, the result might show differently.

J. J. R. CROES, M. Am. Soc. C. E.—I think Mr. Emery stated yesterday that water power was not reliable. I would like to know how he arrived at that conclusion?

CHARLES E. EMERY, M. Am. Soc. C. E.—My statement was that on streams which were intermittent, the water power was not reliable, and that in many such cases, where it is necessary to maintain two plants, it

would be found more economical to depend upon steam power entirely, but I would hardly suppose that here at the Falls of St. Anthony, with the whole volume of the Mississippi behind them, the water power could very well be considered unreliable.

It may be noted, however, that a paper of Mr. J. P. Frizell, read subsequent to the above discussion, shows that the volume of the Mississippi at the Falls of St. Anthony is so variable that storage reservoirs are desirable, so that my suggestions in reference to steam power are directly applicable to that case.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CCLXV.

(Vol. XII.—October, 1883.)

THE WATER-POWER OF THE FALLS OF ST. ANTHONY.

By JOSEPH P. FRIZELL, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, ST. PAUL, MINN., JUNE 21ST, 1883.

WITH DISCUSSION.

Thirty years ago this summer the land now occupied by Minneapolis proper, that is, the west side of the river, previously included in the military reservation of Fort Snelling, was thrown open to settlement and taken up on pre-emption claims. At the same time a town had been established on a permanent and substantial basis only 8 or 9 miles distant, which had already become a place of note and importance and the capital of the territory.

We find here to-day a city said to contain 100 000 people, with broad streets, beautiful residences, fine buildings, and industries whose annual products are counted by tens of millions. In Boston, New York and Philadelphia six generations of men passed away while those towns were attaining the development that this city has reached in a single generation. This astonishing result is due wholly to the water-power

furnished by the Falls of St. Anthony. Having been for several years connected with this water-power, as engineer, on behalf of the United States Government, and, to some extent, on behalf of the owners, I will employ the few minutes allotted me, in a history and description of the same from an engineering point of view.

The total fall here, on land owned as an appurtenance to the water-power, is about 70 feet. The total fall beween Minneapolis and St. Paul is 110 to 115 feet. The greatest fall used, in the ordinary condition of the river, is about 50 feet. The average fall on which the water is used is probably not over 37½ feet.

The drainage ground above the Falls of St. Anthony is a little over 20 000 square miles.

The rainfall in this country is about 30 inches per annum, being rather less than two-thirds that in New England and New York. The amount of water collectable from a given drainage area is even less in proportion than the rainfall. It rarely exceeds 9 inches per annum, and sometimes falls below 6.

The quantity of water that can be utilized for mills operated continuously, and wholly by water-power, is the low-water volume of the stream. Anything in excess of this must be used subject to interruption, or in connection with steam-power. The river at Minneapolis has not, during my acquaintance with it, fallen below 4 000 cubic feet per second, while free from ice. The lowest water, however, occurs in winter. The long periods of steady cold weather occurring in this climate exhaust the sources of the streams, and they fall very low. I measured the Mississippi above Minneapolis several times in March, 1881. I used a current-meter, operating through holes cut in the ice, which had at that time attained, at some points, the enormous thickness of 42 inches. The holes were 25 feet apart. The current was measured immediately below the ice, at mid depth, and just above the bottom, at each hole. The meter was very carefully rated under my supervision, and the measurement is believed to be correct.

The lowest volume was 3168 cubic feet per second, which, on the average fall of 37½ feet, gives, with water wheels of ordinary construction, about 10 000 horse power as the present available power at this point. Being used night and day, this is fully equivalent to 20 000 horse power used during the day alone. By bringing the entire fall into use, this amount could be nearly doubled. It could be still further increased by

the construction of storage reservoirs on the head waters of the stream; and, of course, a large additional quantity of power could be leased, subject to interruption, supplemented by steam power. In this connection it may be stated that sawdust, equivalent in steam-producing power to not less than 20 000 tons of coal, is annually thrown into the river at this point.

This arrangement of nature, by which the lowest water occurs in the winter, has some advantages for the milling interest. 1. The saw-mills run only while the river is open, and their demands cease before extreme low water occurs. 2. When the business increases to that degree that auxiliary steam power is required, the waste steam from the engines will afford an economical means of heating the mills. In New England, low water occurring mainly in the latter part of the summer and autumn, this advantage is largely lost.

The following figures will show the advantage to be expected from reservoirs. The United States Engineer Department gauged the river at Crow Wing, about 130 miles above Minneapolis, where the drainage area is about $\frac{5}{13}$ of that commanded by the Falls of St. Anthony. The gaugings were continued for a year, commencing November, 1881. Assuming that the flow at Minneapolis was the same as at Crow Wing, in proportion to the extent of drainage ground, I have the following results:

Flow in Nov., 1881,	31 646	millions of cub.	ft.	=	13 081	cub.	ft.	per sec.
" Dec., "	24 016	"	"	"	8 967	"	"	
" Jan., 1882,	16 988	"	"	"	6 343	"	"	
" Feb., "	13 406	"	"	"	5 542	"	"	
" Mar., "	16 696	"	"	"	6 234	"	"	
" April, "	63 705	"	"	"	24 577	"	"	
" May, "	81 910	"	"	"	30 582	"	"	
" June, "	67 438	"	"	"	26 017	"	"	
" July, "	61 051	"	"	"	22 794	"	"	
" Aug., "	35 605	"	"	"	13 293	"	"	
" Sept., "	25 053	"	"	"	9 665	"	"	
" Oct., "	37 324	"	"	"	13 091	"	"	

The quantity for November, 1881, includes only 28 days of that month, and October, 1882, includes two days of the following month. The minimum volume of the river, deduced in the same manner as the

above, was 5 243 cubic feet per second, being much above the minimum of ordinary years. This is the greatest quantity that could have been leased during that year and guaranteed free from interruption. It will be noticed that January, February and March are the only months which fall below 24 000 millions, the aggregate deficiency being 24 910 millions. This quantity of water held in storage would have raised the available volume of the river from 5 243 to 9 259 cubic feet per second, and have enabled the latter quantity to be leased, free from interruption, the year round; that is, it would have increased the water power at Minneapolis by 77 per cent. In a year of ordinary or extreme low water, like 1881, the value of such a reserve of water would have been greater, probably doubling the available milling volume of the stream at Minneapolis.

Whether the reservoirs now in course of construction by the United States Engineer Department will be of much benefit to this water power is open to doubt. These reservoirs are supposed to be constructed wholly in the interest of navigation. They are intended to intercept waters not required for navigation, and discharge them when they are so required. This use of the reservoirs would undoubtedly prevent the river from falling very low at Minneapolis during the season of navigation, but could be of no benefit to the mills in winter, when their need of such aid is greatest, no discharge being required at that season for purposes of navigation. Moreover, the most effectual use of the reservoirs would require them to intercept the entire flow of their respective drainage areas during the winter, to the great and manifest injury of the milling interest. Whether the millers have acquired any prescriptive rights as against the sovereign authority, which would prevent this use of the reservoirs, is a question for the lawyers.

The geological formation here is St. Peter sandstone, capped by Trenton limestone; but the northerly limit of the latter, in the bed of the river, is only 400 yards above the present brink of the falls. The limestone in the bed of the river is 12 to 14 feet thick at the brink of the falls, diminishing up stream. It lies in horizontal strata, intersected with vertical seams. Some of these strata disintegrate wholly on exposure to the air; others form a very fair building stone, of which you will see many examples in Minneapolis and St. Paul.

The St. Peter sandstone, commonly called the sand rock, is rock only in the geological sense. It exhibits some appearance of stratification, and some strata are harder than others. It is nowhere so soft that it

will not stand vertically, except when saturated with water, and nowhere so hard that it cannot be worked with the pick. The softest stratum at the falls is 16 to 22 feet below the bottom of the limestone. The attempt to excavate in this stratum, and to keep excavations clear by pumping, has resulted in extensive and dangerous cavities. The sandstone formation extends to a depth of 140 or 150 feet below the bottom of the limestone, where a rock is encountered of the hardness of granite.

This formation has been of great advantage in the development of water power, on account of the facility with which races are executed in it for discharging the water after passing the wheels. In ordinary situations, the mills must be placed between the canal of supply and the river or canal of discharge. Here their location is limited by no such restriction, those which are placed outside of the canal of supply carrying their tunnels under the same to reach the river. There is, probably, no example in existence of so large an amount of power derived from so short a canal. This method has worked admirably so long as the discharging tunnels have been but little below the lime rock, utilizing about one-half the total fall. It becomes more difficult and expensive when the tunnels are carried deeper. An attempt to make the entire fall available at existing establishments by this means would encounter great and, perhaps, insurmountable difficulties.

The water power is owned by two companies, the Minneapolis Mill Company occupying the westerly shore, the St. Anthony Falls Water Power Company the easterly. These companies obtained their charters from the Territorial Legislature of Minnesota in 1857, and proceeded to build the existing system of dams, which were constructed solely with reference to facilities for handling and sawing logs. To facilitate these operations the channel between Hennepin Island and the east shore was closed by a dam. Another dam was extended from the westerly shore some 400 feet into the main channel of the river. A third dam was built on the west side of Hennepin Island. These dams reduced the overflow, which previously had a development of some 1 200 feet, to less than 500.

These measures were immediately followed by an alarming increase in the rate of recession of the falls. Professor Winchell, our State geologist, has published in the Report of the Geological Survey of Minnesota a very interesting speculation as to the probable date of the last glacial epoch, at which time he supposes the cataract to have been at the

present site of Fort Snelling. He finds from the statements of travelers who have visited and roughly surveyed the falls at different times, previous to the use of the water power, that they were receding at the average rate of 4 or 5 feet per annum. Between 1857 and 1868 the recession was about 288 feet, some 200 feet of which occurred between 1866 and 1868.

The narrowing of the overflow and consequent concentration of the current had another bad effect. It increased the fall. Of this there is the most direct historical evidence. Lieut. L. M. Pike visited the Falls of St. Anthony, September 30th, 1805. His journal, published in London in 1811, is entitled "Exploratory Travels through the Western Territories of North America in 1805–6 and '7." He details certain surveys and measurements that he made at the falls, and among other things says: "The perpendicular fall of the chute is 16½ feet." Major Stephen H. Long, who visited the falls in 1817, says: "The perpendicular fall of the water, as stated by Pike in his journal, is 16½ feet, which I found to be true by actual measurement. To this height, however, 4 or 5 feet may be added for the rapid descent which immediately succeeds the perpendicular fall within a few yards below." At present the descent of the water at the overflow is over 36 feet. Some 5 feet of this is due to a low dam at the brink of the fall, intended to keep the limestone flooded with water. This gives a present fall of over 31 feet against 20 or 21, which was all that could be made of it at the time of Major Long's visit in 1817. If we take into account the depth that the water would have on the limestone in the absence of all dams, it is apparent that the effective fall acting on the bottom has been doubled.

In the fall of 1868 a tunnel was commenced under license from the St. Anthony Falls Water Power Company, designed to serve as a raceway for mills located on Nicollet Island, something like 1 000 feet above the present brink of the falls. Being conducted in utter disregard of the precautions which ordinary foresight would suggest, it resulted in opening a passage for the water under the limestone.

The millers and citizens finding the water power thus threatened in front and rear, became much alarmed, and bestirred themselves with alacrity to avert a catastrophe. Several hundred thousand dollars were raised by the city of Minneapolis by the issue of its bonds, and the matter being presented to Congress, it was regarded as sufficiently national to warrant the general Government in undertaking the preservation of

the falls. Works for this purpose were carried on jointly by the city and the general Government. The latter assumed and still exercises control over these works. The openings admitting the water under the limestone were surrounded by coffer-dams; cavities accessible from above were filled with gravel and covered with pavement. The tunnel, which was originally 6 feet square in cross section, and had been greatly enlarged by the action of the water, was lined with timber backed with concrete. This lining having been crushed in by the pressure of water during the progress of the work, the additional precaution was taken of filling the cavity for a distance of 250 feet with well-rammed gravel.

A dike of concrete, corresponding to a puddle wall in an ordinary embankment, was constructed entirely across the river, under the limestone. It is about 4 feet in thickness, and extends to a depth of 38 feet below the bottom of the limestone. The existing apron was constructed of crib and stone work, covered with a 12-inch deck of timber. Two low dams were also constructed to keep the limestone flooded in seasons of low water and protect it from the action of the frost. Fuller details of all these works will be found in the report of the Chief of Engineers, U. S. A., for 1879. The total cost of these works of preservation has been something over $900 000.

These works, it is believed, have placed the falls beyond any immediate danger of disappearance. Nevertheless, their condition is far from the permanence demanded by interests of this magnitude. The concentration of the current at its overfall into less than one-third of its original width still continues. The width of the apron at its crest is about 450 feet, and its construction is such that it concentrates the whole volume of water upon a width of about 350 feet at the bottom. The abrasive action of such a current acting on such a confined space is, of course, very severe. Holes to the depth of 40 and even 50 feet have been excavated in the sand-rock. These have been filled up from time to time with boulders and blocks of limestone, but with very unsatisfactory results, the stone being speedily washed out by the action of the water.

A method of protecting the bottom suggested by me has recently been tried by the Engineer Department. It consists in leveling up the bottom with loose stone to the proper height and covering it with broad, flat cribs just deep enough to hold sufficient stone to render them immovable, and furnished with very strong decks of timber. Such a crib

must be kept afloat while filled with stone in order to put on the deck. For this reason it is made water-tight, being nothing else than a flat boat or scow. A tight curb or bulwark reaches above the deck high enough to give the necessary buoyancy to the crib. After being finished it is floated into position and sunk by admitting the water. A crib 80 feet square and 5 or 6 feet deep was very successfully sunk last winter at the point where the abrasion is greatest. This was as much as the funds at the disposal of the department admitted of. A line of such cribs extending the full width of the toe of the apron would, no doubt, arrest the abrasive action for some time. Whether a single crib will be of much service remains to be seen.

These mills, as you have noticed, run night and day, generally starting at 12 o'clock on Sunday night and running till 12 on Saturday night. Most water powers at the East, devoted to the cotton and woollen manufacture, furnish power during the day only, and have facilities for holding the night flow of the stream for use during the day. It is found more economical here to run night and day.

The grants of water that have been made here have been mainly expressed in mill powers, a mill power being about 75 theoretical horse power, or from 50 to 60 effective horse power, according to the efficiency of the wheel and appurtenances. In some cases land has been sold accompanied by the perpetual right to draw certain definite quantities of water without reference to the fall. No systematic effort has thus far been made to restrict the grantees to their stipulated quantities of water, and consequently no attention has been paid, either in the construction of wheels and races, or in the selection of machinery, to the economical use of power. A lease of a quantity of water, unaccompanied by any measures for its enforcement, is simply a license to draw at will, and the lessee seldom fails to act on that construction of it. So long as he is not questioned as to the quantity of water he uses, he sees no occasion for nicety in his means of using it, and rarely incurs any expense that may be avoided by an excessive use of water. The inevitable consequence has followed, viz., that though the amount of machinery here is probably not more than the eighth part of what this water power, properly improved and applied, is capable of maintaining in operation, its present capacity is already reached and exceeded, it being no uncommon thing for mills to stop for lack of water in the season of low water. At such seasons the evils of a lack of control over lessees appear in their worst

form. The mill pond is drawn down to the lowest point that will allow the water to flow through the canals. The canals are swept full of sand which has accumulated in the mill pond during the time of high water, and, by the diminution of the head, the power is largely wasted at the very time when it is of the greatest importance to use it economically.

A conspicuous instance of the misuse of power is furnished by the draft-tubes with which almost every wheel is provided. The usual arrangement of the wheel is this: a vertical shaft is carried well down into the limestone. A shelf or ledge is there left around the shaft, and the latter is carried with diminished diameter through the limestone and to the necessary depth in the sandstone. On this shelf rests the platform which supports the wheel. The water is discharged from the wheel through a draft-tube, which reaches down below the surface of the water in the wheel-pit. The water thus acts not directly, by its weight above the wheel, but indirectly by diminishing the atmospheric pressure below the wheel. These draft-tubes are almost invariably too small. I give a few instances:

A 54-inch "New American" turbine, acting under a head of 48 feet, has a draft-tube 52 inches in diameter. The wheel is stated by the makers to discharge, with full gate, 216.45 cubic feet per second under a head of 40 feet. The effective head, as we shall see, is about 44 feet, and consequently the discharge with full gate should be 227.27 cubic feet per second. This would require a velocity through the draft-tube of 15.41 feet per second, corresponding to a head of 3.69 feet. Adding the frictional head in the draft-tube, assumed to be 24 feet long, we have 4.10 feet for the loss of head at this wheel, or about $\frac{1}{12}$ the total power of the wheel. With the wheel running at full gate, this loss amounts to 1.4 mill powers, worth commercially some $1 400 per annum.

In another mill the proprietor is now putting in a 40-inch Victor wheel, to work under a head of 43 feet, provided with a draft tube 40 inches diameter. We shall find the effective head here to be a little over 37 feet. The discharge, under a head of 37 feet, is given by the makers as 155.3 cubic feet per second. This implies a velocity of 17.8 feet per second in the draft tube, involving a loss of head of 4.92 feet. Adding 0.59 feet for the fractional loss of head in the draft-tube, assumed to be 20 feet long, we have for the total loss of head 5.51 feet, or something over $\frac{1}{8}$ the total power of the wheel. These are only two instances taken at random, and might be multiplied to any extent.

The waste of power is not the only evil result of this gross disregard of the laws of hydraulics. The inordinate velocity with which the water is discharged from the draft-tube is very destructive to the wheel-pit. On one occasion, a miller had used his raceway for a common sewer of his mill, a use which rendered the wheel-pit tolerably safe from inspection. Having occasion to visit it, he found a cavity under the draft-tube some 30 feet in depth. Nothing disconcerted by so trifling an accident, he filled up his pit and set his mill to running again. But when the owner of the adjoining mill, in attempting to deepen his race, pumped up materials recognized as coming from the above mentioned pit, it was felt that the limit of safety had been reached, and the latter enterprise was discontinued.

Some of the millers, with a praiseworthy determination not to be beaten in this combat with the laws of nature, have lined the bottoms of their wheel-pits with boiler-plate. If they would put sufficient iron in their draft-tubes, I think they would have no occasion to use that material in their wheel-pits.

The application of water power to industrial uses at the Falls of St. Anthony has commenced and proceeded with very little aid from civil engineers, properly so called. The engineering practiced here is what is sometimes called common sense engineering, though that term can hardly be applied to the tunnel project above described. It is the kind of engineering that every man of ordinary intelligence is capable of practicing. It has aimed only at immediate results, without regard to remote or indirect consequences—often without much regard to direct consequences. It has been very successful in its immediate objects, but, as might have been expected, has left a heavy legacy of trouble and difficulty for the future.

It is in this point of view that this water power is interesting to engineers. It shows the extent to which this kind of makeshift engineering can be carried, and the consequences to which it inevitably leads. This kind of engineering has here been carried to its culmination. The enterprise has reached a stage where makeshifts will no longer serve. No material extension of these industries is possible without the adoption of some more rational, comprehensive and scientific methods of procedure in the management of the water power.

The methods and appliances adopted were admirably well suited to the requirements of the work at its commencement. The disposable

capital was limited. It was necessary to set wheels to running with as little outlay as possible, and all financial, legal and engineering niceties had to be disregarded; but the enterprise has now outgrown these methods, as the town has outgrown the huts and cabins which served for shelter in its early days.

The adoption of any comprehensive plan of improvement is now beset with the accumulated embarrassments of twenty years of makeshift—embarrassments not wholly physical, but largely of a legal character. Any plan embracing, as it should, the preservation of the falls, in connection with the development of the water power, must have the concurrence and co-operation of three parties: the Minneapolis Mill Company, the St. Anthony Falls Water Power Company, and the United States Government—a concurrence hardly to be hoped for.

Disclaiming any intention of offering advice to the parties interested, and commenting on this case simply as a problem in engineering, I observe that there are three things to be done before any comprehensive plan of permanent improvement will be possible.

1. The United States Government must be induced to withdraw wholly from the work, leaving the preservation of the falls to the owners of water power. The embarrassments incident to this connection are not compensated by the small sums which the Government occasionally devotes to this work, and reliance upon what can be done with such limited means is the surest way to invite disaster.

2. The two companies controlling the water power must be united under one management. In no other way can the preservation of the falls, the distribution of the water, the construction of reservoirs, the maintenance of legal rights, and other interests common to the water power be efficiently managed.

3. The natural channels of the river must be restored to it. Throwing the drainage of 20 000 square miles, with a fall of 36 feet in a sheet 350 feet wide, upon a bed of indurated sand, is not an arrangement calculated to stand the test of years. The maintenance of the falls under these conditions cannot be pronounced impossible, but the expense and danger attending it cannot be compensated by the trifling advantage of using the bed of the stream for mill sites.

These preliminary difficulties being removed, would leave the ground clear for the adoption of plans which would make this water power, leaving Niagara Falls and its possibilities out of account, the largest on the continent.

DISCUSSION.

N. M. EDWARDS, M. Am. Soc. C. E.—I would ask the method of leasing the power?

Mr. FRIZELL.—The leases were mainly copied from the forms prevailing in New England, at Lowell and Lawrence, describing the mill power as, in effect, such a quantity of water on such a head, that the product of the quantity of the water in cubic feet per second by the fall in feet is 660. There is a clause allowing for loss of head in races, but that is practically what it amounts to.

Mr. EDWARDS.—I would state that in Wisconsin, on the lower Fox River, the outlet of Lake Winnebago, there are parties that lease water power by the square inch, sometimes not mentioning the head, in other cases giving the number of square inches and the feet head. How should the power be estimated? So far as I can find, there has been no decision in Wisconsin courts upon this special question. It, I think, must come up for a decision soon.

I would request information as to any local custom, or any court decisions upon how the power is, under similar leases, determined. Whether, *first*, the flow under the conditions of a wheel in labor, taking the square inches as the total cross section of least aperture through the wheel; or, *second*, the actual flow through an opening equal to the square inches given in lease, said opening having sharp edges, and under the head of water specified; or, *third*, the theoretical fall due to that cross section and head.

F. P. STEARNS, M. Am. Soc. C. E.—I once had occasion to take some measurements at a place where water was sold to the different mill owners by the square inch. I tried to find the meaning of the term, and from several sources learned that it was the discharge which would pass through an orifice one square inch in area if there were no contraction and the water had the *theoretical* velocity due to the head. Many of the makers of turbines give the discharge of their wheels in "square inches," and this term, as used by them, agrees with the definition I have given. Information from some other sources led me to believe this definition was not universally accepted.

Mr. EDWARDS.—Where was this water power you have referred to?

Mr. STEARNS.—At Big Rapids, Michigan.

F. Collingwood, M. Am. Soc. C. E.—I was once called upon to measure the amount used upon the various wheels of Williamsburg, and I found all that I was expected to do was simply to measure the orifices next to the wheels, so many inches, no matter what the wheel was. They were all turbines.

Mr. Stearns.—I might state that the engineer who had been there before I was, had measured the number of square inches of the canal leading to the wheel, regardless of the head.

Mr. Frizell.—I will say in reference to leasing water by orifices, if you make an orifice of twenty square inches—supposing the head not to vary at all—you could change your orifice without changing the area of it, so as to nearly double the quantity of water, without making any change whatever in the area of the orifice, by adding such appliances on one side or the other of the dam or wall in which the orifice is situated as to make the quantity vary very materially—50, or even 100 per cent. I always advise people not to lease water by orifices.

Jas. B. Francis, M. Am. Soc. C. E.—That difficulty seems to have been foreseen at Lowell, and they have avoided it. A certain number of cubic feet of water per second has been leased, leaving it to the parties to make the best use of it they can, and to measure it in any way that might be devised and that the progress of science might indicate. The result has turned out to be very fortunate in avoiding uncertainties and disputes. This practice has been followed in Lowell since 1825, and has probably been adopted in many other places.